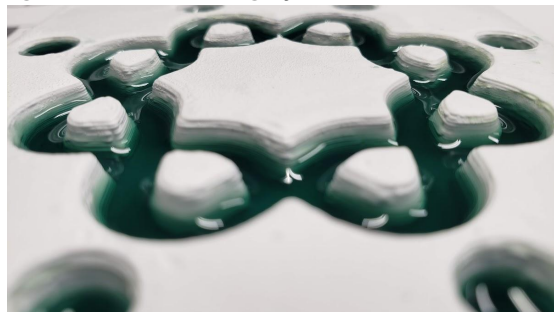


Visualizing Carbon Capture

February 28, 2023

Overview

Our flagship product, COOSorbent, will be a passive, modular, biogas upgrading solution for small and medium size dairies. We're on a mission to decommission 82 MT-CO₂e from manure management in US agriculture.^[1] This highly-chemical selective Sodium Carbonate sorbent is fueling raw innovation in biogas



by overcoming a critical price point^{[2][3]} for smaller farms, which accounted for >50% of the US dairy inventory.^[4]

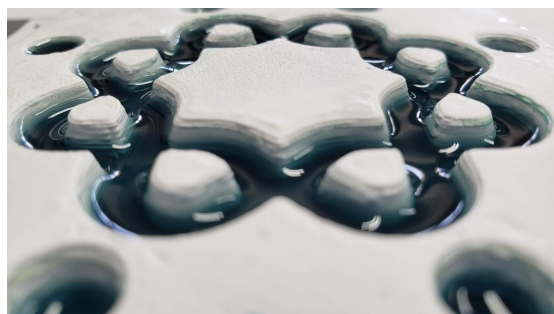
Show-Me Carbon Capture

Using anthocyanins extracted from red cabbage and Sodium Carbonate, we produced a solution to simulate and visualize COOSorbent's carbon capture mechanism.^[2]



pH Indicator

Extracting pH indicators from red cabbage is a classic science fair experiment for students.^[5] Red cabbage contains a myriad of anthocyanins which change color with pH^[5] as CO₂ gets absorbed by the solution.



Red Cabbage *Brassica oleracea* v. *capitata*

The primary anthocyanin found in red cabbage is cyanidin-3-diglucoside-5-glucoside.^[6] Hydrothermal extraction enables rapid, facile, chromatic assays across the pH spectrum ($0 \leq \text{pH} \leq 14$). Phenolphthalein has been previously demonstrated by Lawrence Livermore National Laboratory to indicate CO₂ capture by the sorbent^[6]. Phenolphthalein is one of the many polyphenols found in red cabbage.

Methodologies

We created a 3D CAD model of the Breakthrough Energy Ventures logo from a SVG file we generated from the web. We then printed the design using a FlashForge Creator Pro 3D printer using ABS filament. We used hydrothermal extraction methods to create a pH indicator using the red cabbage, harvesting the anthocyanins. Using our hydrothermally extracted anthocyanins (pH indicator) solution, we made a basic Sodium Carbonate solution similar to the MicroEncapsulated Carbon Dioxide Sorbent (MECS) that will be used in COOSorbent. We used a syringe to fill in the custom 3D printed Breakthrough Energy logo with our pH indicating solution. We mixed a 5% Acetic Acid solution (vinegar) with Sodium Bicarbonate as a CO₂ source, capturing CO₂ inside a latex balloon before releasing into a sealed chamber with the logo.

Sensing Carbon Dioxide

To help verify air quality improvements, we developed a basic air quality sensor using an Elegoo Uno R3 (Arduino) and MQ-135 Carbon Dioxide sensor along with ChatGPT to write a custom algorithm for our sensor to output CO₂ levels in parts per million (ppm). We wired the MQ-135 by analyzing the algorithm written by ChatGPT and a breadboard. Setup took less than 5 minutes. We feel this is great for education!

Our market research directly indicates perceptions surrounding biogas technologies poses an opportunity for innovation! A case study in Pixley, California found that neighbors in the region want to see how biogas improves air quality in their communities. Our open-source solutions will help provide round-the-clock monitoring at installations. This development stage is a critical initial step before transitioning from chemiresistive technologies towards more precise Non-Dispersive Infrared (NDIR) technologies at installations. This demo sensor was made using OpenAI, open source hardware and software, and commercially available off-the-shelf components anyone could use to verify CO₂ levels at their facility.

Seeing is Believing

As our Sodium Carbonate solution absorbs Carbon Dioxide, the pH of the solution falls from around 10.5 down to about 8.5 becoming a Sodium Bicarbonate solution. The resulting shift in Hydrogen & Hydroxyl ions (ΔpH) chemically alters the anthocyanins in our solution, thus causing color to shift from Green to Blue. Thus, carbon capture in biogas upgrading can be understood visually.

Carbon capture and biogas upgrading are rich and complex topics. Methane and Carbon Dioxide are both invisible gasses. We also sought to demonstrate the viability of open-source hardware and software and AI and for addressing consumer perceptions about biogas. More importantly this project demonstrates a straightforward and simple way of visualizing chemical mechanisms used for upgrading biogas. Even in an era of modern technology and artificial intelligence: a picture is still worth a thousand words!

Appendix A: ChatGPT Code

On 20 February 2023, the following prompt was used to generate the algorithm for our CO₂ sensor using ChatGPT from OpenAI:

Can you please code a MQ-135 CO2 sensor to detect Carbon Dioxide using Arduino?

Return

```
// MQ-135 CO2 Sensor Code
// Author: ChatGPT

const int CO2_PIN = A0; // Define analog input pin for the sensor

void setup() {
  Serial.begin(9600); // Initialize serial communication at 9600 bps
}

void loop() {
  int sensorValue = analogRead(CO2_PIN); // Read sensor value
  float voltage = sensorValue * (5.0 / 1023.0); // Convert sensor value to voltage
  float ppm = 5000.0 * (voltage - 0.1) / 4.9; // Calculate CO2 concentration in parts per million (ppm)

  Serial.print("CO2 concentration: ");
  Serial.print(ppm);
  Serial.println(" ppm");

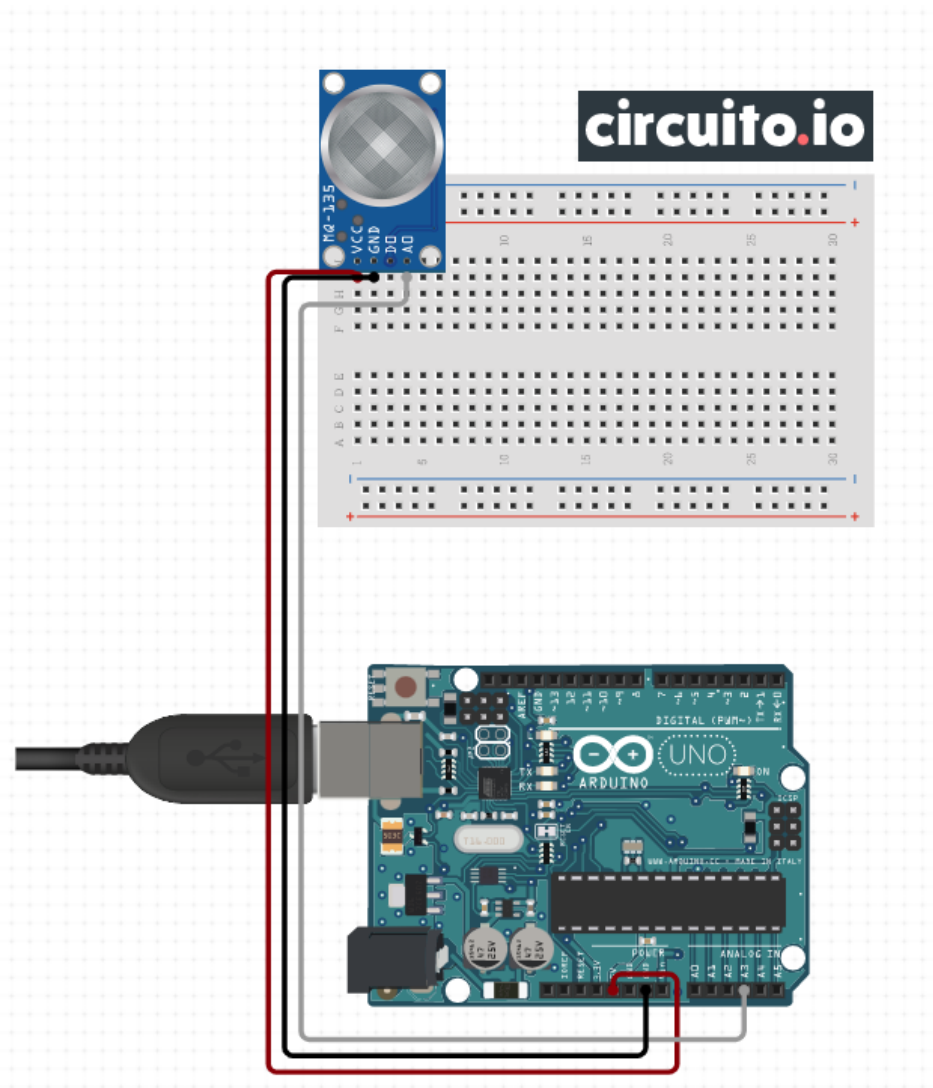
  delay(1000); // Wait for 1 second before taking the next reading
}
```

Learn more at <https://openai.com/blog/chatgpt/>

Appendix B: Wiring Diagram

We used circuito.io to rapidly generate a wiring diagram for our CO₂ sensor.

Source: <https://www.circuito.io/app?components=512,11021,398790>



Appendix C: Parts List

We used circuito.io to rapidly generate the parts list for our CO₂ sensor. We then integrated that parts list into the table format you see below using Google Docs.

Source: <https://www.circuito.io/app?components=512,11021,398790>

Item No.	Quantity	Description	Price
2.0	1	BreadBoard (½ size)	\$4.50
2.1	1	Arduino Uno	\$23.38
2.2	1	USB Cable A to B	\$3.26
2.3	1	Gas Sensor MQ-135	\$1.46
2.4	1	Jumper Wires M/M	\$1.95
Total			\$34.55

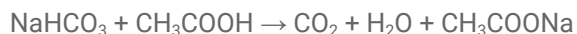
Note: Open-source hardware and digital manufacturing are revolutionizing modern technology. Several alternatives to the Arduino Uno exist, many for less than \$10. The Elegoo Uno R3 used in this project retails for \$12.98.

Note: For continuous data collection and gas monitoring, IoT communication becomes pertinent. Several off-the-shelf options exist including Arduino Wifi bonnets, Arduino Mini, Raspberry Pi, et al. This will raise the cost of this open-source project.

Note: Typical CO₂ concentrations in biogas are 300,000 - 400,000 ppm (30-40%). The MQ-135 is rated up to 1,000 ppm. Our other meter, a Temtop M2000C, is rated up to 5,000 ppm.

Appendix D: Creating a Source of CO₂

We evolved Carbon Dioxide from a neutralization reaction involving Sodium Bicarbonate and Acetic acid, thereby forming Carbon Dioxide Gas, Water, and Sodium Acetate. The balanced stoichiometric equation and relevant calculations are shown below.



$$\rho_{\text{CH}_3\text{COOH}} = 1.049 \text{ g/mL} \approx 1.05 \text{ g/mL}$$

$$\rho_{\text{H}_2\text{O}} = 0.9982 \text{ g/mL} \approx 1.00 \text{ g/mL}$$

$$\%(v/v)_{\text{Vinegar}} = 5\% \text{ vol}$$

$$V_{\text{Vinegar}} = 100 \text{ mL} \Rightarrow V_{\text{CH}_3\text{COOH}} = 5\% \text{ vol} * V_{\text{Vinegar}} = 5 \text{ mL}$$

$$m = \rho \times V \Rightarrow m_{\text{CH}_3\text{COOH}} = \rho_{\text{CH}_3\text{COOH}} \times V_{\text{CH}_3\text{COOH}} = (1.05 \text{ g/mL}) \times (5 \text{ mL})$$

$$\therefore m_{\text{CH}_3\text{COOH}} = \mathbf{5.25 \text{ g}}$$

$$M_{\text{CH}_3\text{COOH}} = 60.052 \text{ g/mol} \approx 60.1 \text{ g/mol}$$

$$n = m / M \Rightarrow n_{\text{CH}_3\text{COOH}} = (m_{\text{CH}_3\text{COOH}}) / (M_{\text{CH}_3\text{COOH}}) \Rightarrow n_{\text{CH}_3\text{COOH}} = (5.25 \text{ g}) / (60.1 \text{ g/mol})$$

$$\therefore n_{\text{CH}_3\text{COOH}} = \mathbf{0.0874 \text{ mol}}$$

$$M_{\text{NaHCO}_3} = 84.0 \text{ g/mol}$$

$$m = n \times M \Rightarrow m_{\text{NaHCO}_3} = (n_{\text{NaHCO}_3}) \times (M_{\text{NaHCO}_3}) \Rightarrow m_{\text{NaHCO}_3} = (0.0874 \text{ mol}) \times (84.0 \text{ g/mol})$$

$$\therefore m_{\text{NaHCO}_3} = \mathbf{7.34 \text{ g}} \quad \text{Note: Sodium Carbonate is hygroscopic. Actual mass may vary with hydration.}$$

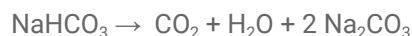
$$M_{\text{CO}_2} = 44.0 \text{ g/mol}$$

$$m = n \times M \Rightarrow m_{\text{CO}_2} = (n_{\text{CO}_2}) \times (M_{\text{CO}_2}) \Rightarrow m_{\text{CO}_2} = (0.0874 \text{ mol}) \times (44.0 \text{ g/mol})$$

$$\therefore m_{\text{CO}_2} = \mathbf{3.85 \text{ g}} \quad \text{Note: At STP this is approximately 2 L of CO}_2$$

Appendix E: Sodium Carbonate Solution Preparation

At temperatures around $T = 80^{\circ}\text{C}$, Sodium Bicarbonate will decompose into Sodium Carbonate, Carbon Dioxide, and Water.^[3] This forms the foundation of COOSorbent's regeneration cycle.^[3]



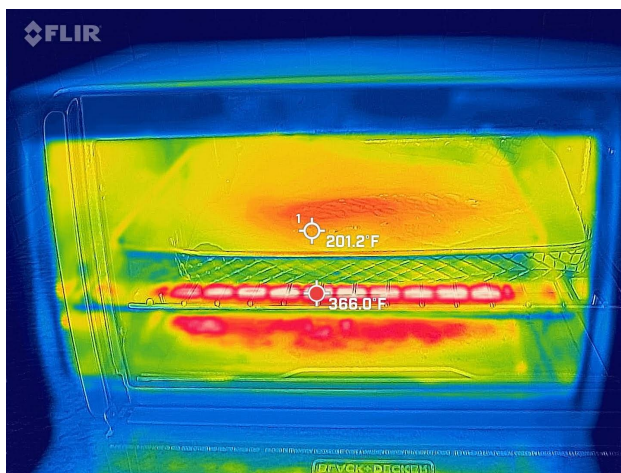
Utilizing the stoichiometry obtained in Appendix D, we can directly calculate the maximum mass of Sodium Carbonate that can be neutralized by the volume of Carbon Dioxide gas evolved.

$$M_{\text{Na}_2\text{CO}_3} = 106.0 \text{ g/mol}$$

$$m = n \times M \Rightarrow m_{\text{Na}_2\text{CO}_3} = (n_{\text{Na}_2\text{CO}_3}) \times (M_{\text{Na}_2\text{CO}_3}) \Rightarrow m_{\text{Na}_2\text{CO}_3} = (0.0874 \text{ mol}) \times (106.0 \text{ g/mol})$$

$$\therefore m_{\text{Na}_2\text{CO}_3} = \mathbf{9.26 \text{ g}}$$

Utilizing a toaster oven at approximately 120°C , we prepared 14.1 g of (hydrous) Sodium Carbonate by thermal decomposition of approximately 16.5 g of (hydrous) Sodium Bicarbonate for 60 minutes. We verified the reaction temperature using a FLIR One camera.



Chemical decomposition was verified by pH by mixing indicator solution, which produced a vibrant green hue; indicating a pH of about 10.5. A Sodium Carbonate solution was prepared by mixing 50 mL of reverse osmosis water and 4.0 g of Sodium Carbonate, heating to 43.2°C , and mixing with a stir plate on medium for approximately 1 minute. Residual hydration is assumed.

Note: This experiment was conducted using off-the-shelf, commercially and locally available, hydrous forms of Sodium Bicarbonate. Sodium Carbonate was not dehydrated since the reaction never reached 100°C inside the toaster oven. Therefore, it is assumed that the Sodium Carbonate powder was a hydrated formulation prior to solvation. Based on literature review, it assumed that the resulting compounds are nahcolite (NaHCO_3) and trona ($\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot 2\text{H}_2\text{O}$).

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